Cell discard and TDMA synchronization using FEC in wireless ATM systems

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Abstract:
The asynchronous transfer mode (ATM) employs header-error control (HEC) to protect the ATM cell header from bit error and/or avoid the misforwarding of ATM cells. However, wireless ATM systems require a more powerful forward-error correction (FEC) scheme to offer acceptable bit-error rate (BER) performance. This paper proposes the utilization of FEC, which makes it possible to discard ATM cells more reliably. Time-division multiple-access (TDMA) is very suitable for wireless ATM systems. In the TDMA scheme, synchronization is very important. This paper also proposes to combine FEC with unique word (UW) detection for improving TDMA synchronization characteristics

Index Terms:
asynchronous transfer mode coding errors cyclic codes error statistics forward error correction radio networks synchronisation telecommunication networks time division multiple access ATM cell header BER performance FEC TDMA synchronization asynchronous transfer mode bit error bit error rate cell discard cyclic code forward error correction header error control time division multiple access unique word detection wireless ATM systems

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Cell Discard and TDMA Synchronization Using FEC in Wireless ATM Systems

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***Abstract*—The asynchronous transfer mode (ATM) employs header-error control (HEC) to protect the ATM cell header from bit error and/or avoid the misforwarding of ATM cells. However, wireless ATM systems require a more powerful forward-error correction (FEC) scheme to offer acceptable bit-error rate (BER) performance. This paper proposes the utilization of FEC, which makes it possible to discard ATM cells more reliably. Time-division multiple-access (TDMA) is very suitable for wireless ATM systems. In the TDMA scheme, synchronization is very important. This paper also proposes to combine FEC with unique word (UW) detection for improving TDMA synchronization characteristics.**

***Index Terms*— Cell discard, FEC, TDMA synchronization, wireless ATM.**

I. Introduction

Wireless asynchronous transfer mode (ATM) systems have been proposed for future broadband multimedia personal communications [1]–[3]. In those systems, ATM cells are transmitted via radio frames between a central station (B-CS) and user radio modules (B-RM) as shown in Fig. 1.

Because wireless ATM offers the benefits of high transmission speed, bandwidth flexibility, and modular construction in units of cells, time-division multiple-access (TDMA) is suitable as the access system. In this paper, forward-error correction (FEC) and TDMA synchronization are studied for transmitting ATM cells through TDMA radio systems.

Since multimedia services require a high quality level for video and/or data transmission, FEC is essential for multimedia wireless ATM systems [4], [5]. Error correction of the ATM header is especially important because bit errors in the header cause serious control problems, such as the incorrect forwarding of ATM cells.

TDMA systems commonly use the unique word (UW) scheme for frame and/or burst synchronization. Burst false-detection and burst misdetection of the UW's can degrade service quality.

In this paper, we apply FEC to the ATM cell header to counter ATM cell header errors and so reduce cell loss and cell misinsertion. We also propose a TDMA synchronization method that combines UW usage with FEC. An examination is made for the case wherein a cyclic code is used as FEC. This method improves TDMA synchronization characteristics.

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II. ATM Cell Discard and FEC

This section proposes a scheme that discards corrupted ATM cells by using powerful FEC. In this scheme, FEC is utilized to not only correct transmission path errors, but also discard ATM cells.

A. Performance of HEC in ATM

In ATM systems, the cells contain header-error control (HEC) as standardized in the ITU-T and ATM Forum. HEC is a single-bit error correction and multiple-bit error detection code that is employed only in the ATM cell header to avoid incorrect forwarding due to header error. HEC's control eight reduction bits and 40 bits in the cell header.

Let the receiving bits be $R(x)$ and HEC's generator polynomial be $G(x)$. $R(x)modG(x)$ is called the syndrome. One syndrome pattern means that with no error ($R(x)modG(x) = 0$). There are 40 patterns indicating single-bit errors ($R(x)modG(x) = x^i modG(x)$ ($i = 0, 1, 2, \cdots, 39$)), and other patterns indicating multiple-bit errors. HEC operates in two modes: the correction mode and the detection mode. In the correction mode, a single-bit error can be corrected and cells with multiple-bit errors are discarded. In the detection mode, all cells with detected errors in the header are discarded.

If the output syndrome in the case of multiple-bit errors is one of the 41 syndrome patterns indicating either no error or single-bit error, cell misinsertion is created.

When

$$E(x)modG(x) = 0$$

the decision is that there are no errors in the ATM cell header, where $E(x)$ is an error polynomial for multiple errors.

In the case of

$$E(x)modG(x) = x^i modG(x), (i = 0, 1, 2, \cdots, 39)$$

the decision is that a single-bit error exists in the header, even if multiple-bit error had occurred.

B. Performance of FEC in Wireless ATM

In wireless ATM, HEC is not strong enough and a more powerful error correction scheme is needed. The method by which FEC applied to ATM cell header instead of HEC can be effectively used to address cell discard described below.

The proposed FEC cell format is as follows. At the radio link, HEC is removed and more redundant bits are added to support FEC parity checking, which can more strongly

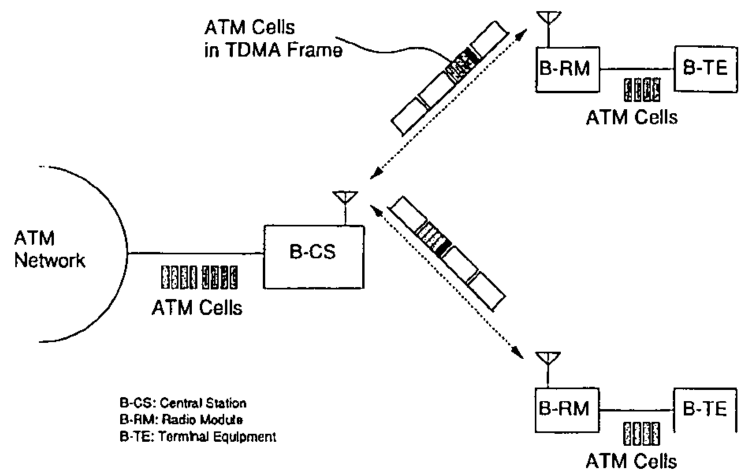


Fig. 1. Constitution of wireless ATM.

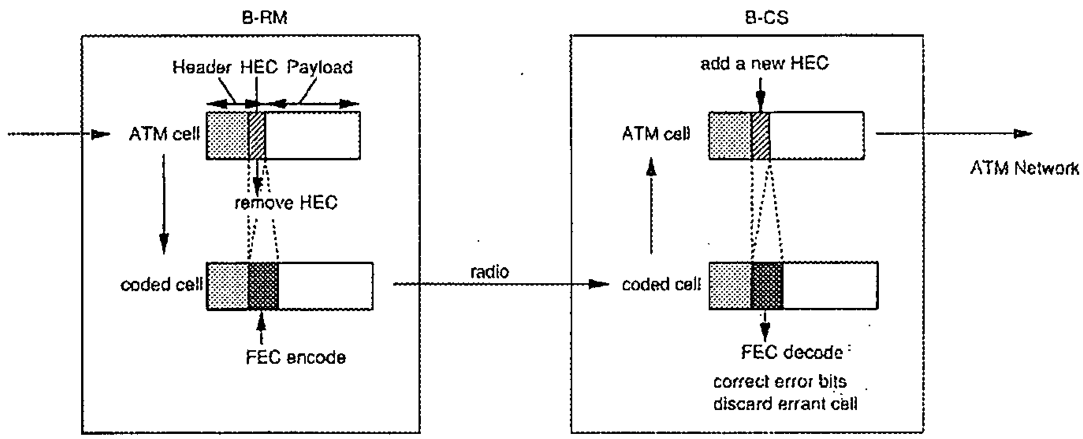


Fig. 2. Adding and removing HEC/FEC redundant bits.

correct the errors occurring in the radio transmission path. The addition/removal of HEC/FEC redundant bits is shown in Fig. 2. In this paper, we apply FEC to only the header, while FEC for the payload should be considered when the quality-of-service (QoS) is discussed.

Fig. 3 shows the relationship between bit-error rate (BER) before FEC and the cell loss ratio, with FEC strength as a parameter. The shortened BCH codes of (44,32), (50, 32), and (56,32) are selected, their FEC strengths, t, correspond to 2, 3, and 4 bits, respectively. As FEC strength increases, cell loss ratio decreases, while the coding rate reduces for compensation.

The following discusses the reduction in the cell misinsertion rate. The t-bit error correction code (n, k) which has $m(= n - k)$ redundant bits cannot correct more than t-bit errors whose occurrence probability is

$$\sum_{j=t+1}^{n} {}_nC_j p^j (1-p)^{n-j} \text{ where } p \text{ is the BER before FEC.} \tag{1}$$

If the syndrome that represents more than t-bit error is calculated (from among the 2^m patterns possible), residual error can be detected and the cell can be discarded correctly. However, when the syndrome is one that represents t-bit or less errors although there are more than t-bit errors, the residual error in ATM header exists, but it cannot be detected and the corrupted cell cannot be discarded. The cell misinsertion rate is represented as

$$P_x = 2^{-m} \sum_{i=0}^{t} {}_nC_i \sum_{j=t+1}^{n} {}_nC_j p^j (1-p)^{n-j}. \tag{2}$$

It must be noted that (2) assumes that the probability of more than t-bit error after correction is given by (1). Fig. 4 shows the relationship between the BER before FEC and the cell misinsertion rate. The cell misinsertion rate is reduced, so cell-discard is more reliable. It is assumed that the bit errors occur randomly for the following reason: since the ATM systems must be broadband, a high radio frequency should be selected such as the millimeter wave band. Millimeter waves have the characteristic of straight line propagation with only slight diffraction. Therefore, the premise of line-of-sight (LOS) communication is valid; the system can be thought of as a power-limited system.

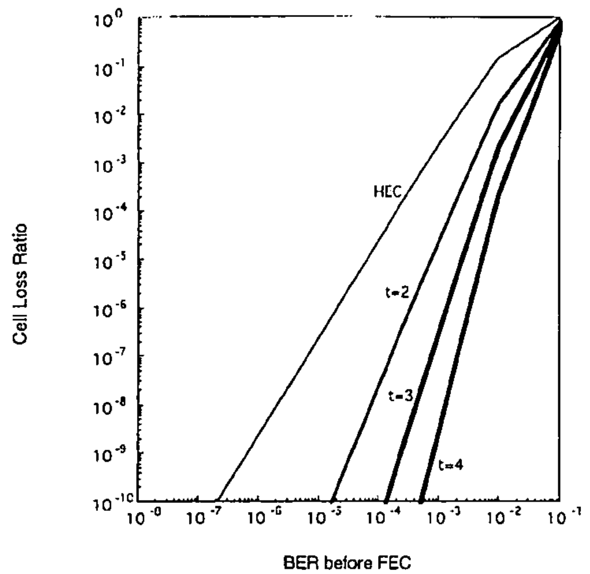


Fig. 3. Cell loss ratio versus BER before FEC.

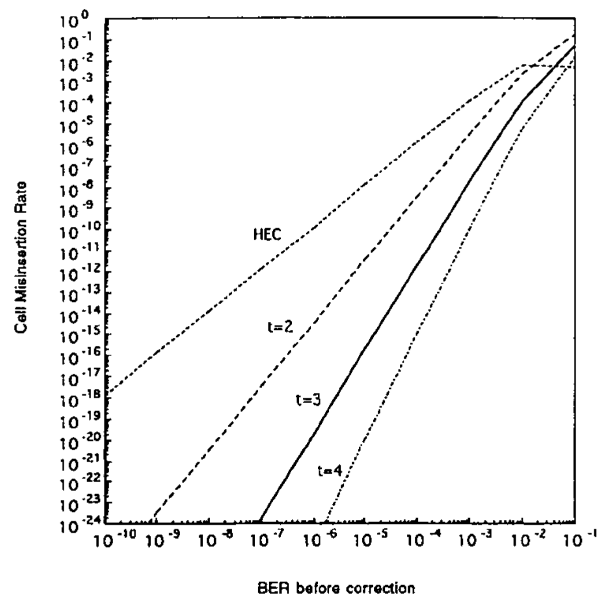


Fig. 4. Cell misinsertion rate.

III. TDMA Synchronization Using FEC

The previous section showed the importance of FEC for wireless ATM systems in reducing transmission error. This section proposes a method that uses FEC for TDMA synchronization of wireless ATM systems. Furthermore, an FEC synchronization technique that uses bit inversion is also proposed.

In TDMA systems, it is common UW's to be used for burst synchronization. Each TDMA burst signal consists of guard time, preamble, UW, and data (coded ATM cell) as shown in Fig. 5. In UW detection, burst misdetection and burst false-detection are important problems. Burst misdetection and false-detection cause data loss and data corruption during

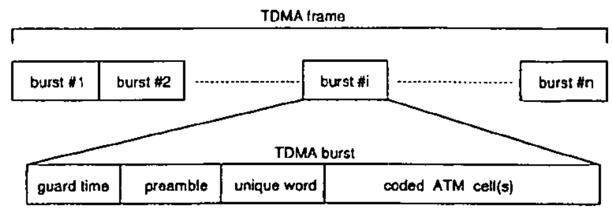


Fig. 5. Constitution of TDMA burst.

one burst, respectively. During the acquisition of TDMA synchronization, burst misdetection influences the acquisition time while false-detection causes false-synchronization. One technique that can reduce false-synchronization probability is repeated burst detection over several successive frames. However, excessive repetition increases the time taken to establish synchronization. This section shows how the utilization of FEC can improve TDMA synchronization characteristics.

A. Burst Synchronization with UW [6]–[8]

The UW misdetection probability is represented as

$$P_m = \sum_{j=\epsilon/2+1}^{N/2} {}_{N/2}C_j p^j (1-p)^{N/2-j}$$

where N is the UW bit length and ϵ is the correlation threshold, assuming the use of QPSK coherent detection and differential logic. The misdetection probability is shown in Fig. 6 for various BER $(10^{-2}, 10^{-3}, 10^{-4})$ and UW length [(a) $N = 16$ b and (b) $N = 32$ b] as a function of ϵ. As ϵ increases, the probability decreases.

The UW false-detection probability is represented as

$$P_f = 2^{-N} \sum_{j=0}^{\epsilon} {}_N C_j$$

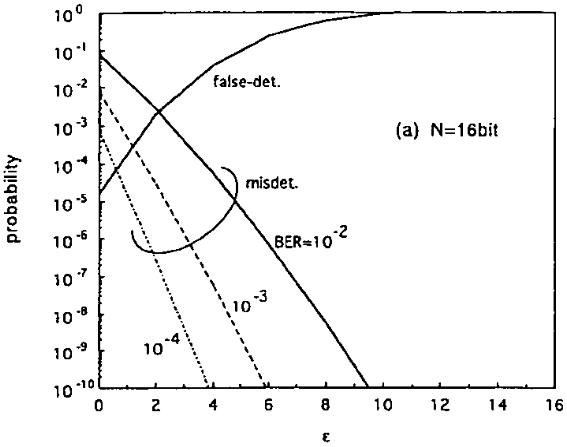
when an open-aperture technique which input the random pattern into the UW detector is applied. The false-detection probability is also shown in Fig. 6.

In order to reduce the UW false-detection probability, we can apply the technique of opening the aperture only near the UW detection timing. This is called the narrow-aperture technique.

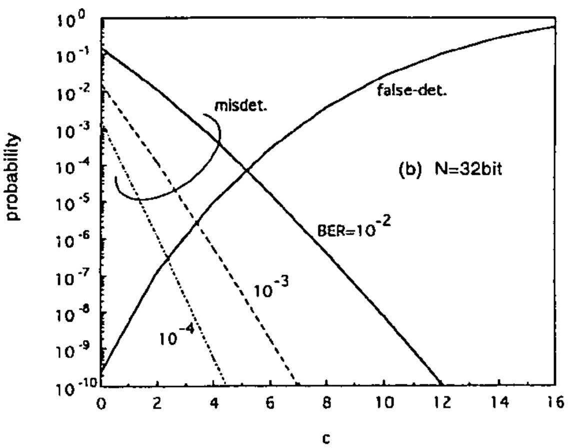
B. Burst Synchronization Using FEC [9], [10]

Using FEC for burst synchronization can further reduce the burst false-detection probability. When both UW detection and bit error correction by FEC are successful, burst synchronization is considered to be successful. If UW false-detection occurs, FEC may not be successful in most cases. Therefore, the burst false synchronization probability is reduced when FEC is applied for synchronization.

With this method, however, if the FEC timing is shifted b-bits from the regular timing by UW false-detection, the probability of the syndrome being zero is 2^{-b}. In order to reduce the probability of false-synchronization caused by shifts



(a)



(b)

Fig. 6. UW misdetection and false-detection probability.

of a few bits, specific bits are inverted at the transmitter side and those bits are inverted again before FEC decoding at the receiver side. The method of bit inversion is as follows.

Transmission bits $T_0(x)$ are written as

$$T_0(x) = \sum_{j=0}^{n-1} a_j x^{n-1-j}.$$

When no error exists, the received bits $R_0(x)$ are

$$R_0(x) = T_0(x).$$

The syndrome S_0 is calculated by putting the root of generator polynomial, α, into $R_0(x)$

$$S_0 = R_0(\alpha) = \sum_{j=0}^{n-1} a_j \alpha^{n-1-j} = 0.$$

When the phase shift is large, the probability of syndrome being zero is $2^{-m}(m = n - k)$.

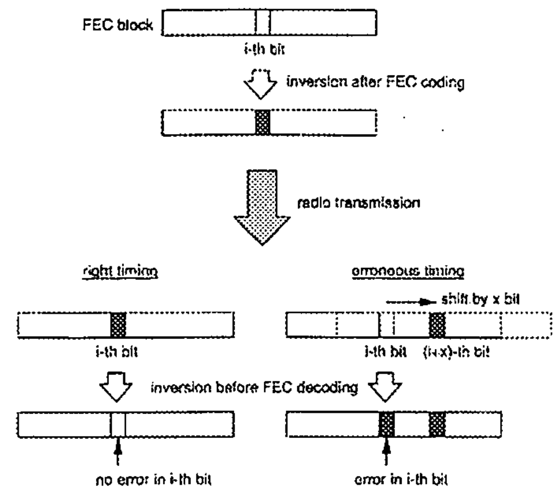


Fig. 7. Bit inversion method.

When the phase shifts by one bit because of UW false-detection

$$R_{-1}(x) = \sum_{j=0}^{n-1} a_{j-1} x^{n-1-j}$$

$$\begin{aligned} S_{-1} =& R_{-1}(\alpha) = \left(\sum_{j=0}^{n-1} a_j \alpha^{n-1-j} \right) \alpha^{n-1} + a_{-1}\alpha^{n-1} \\ &+ a_{n-1}\alpha^{n-1} \\ =& (a_{-1} + a_{n-1})\alpha^{n-1} \end{aligned}$$

if $a_{-1} = a_{n-1}$; $S_{-1} = 0$. This occurs with the probability of 1/2. Similarly

$$\begin{aligned} S_{+1} =& a_0 + a_n \\ S_{-2} =& (a_{-2} + a_{n-2})\alpha^{n-1} + (a_{-1} + a_{n-1})\alpha^{n-2} \\ S_{+2} =& (a_0 + a_n)\alpha + (a_1 + a_{n+1}). \end{aligned}$$

S_{+1} becomes zero with the probability of 1/2, S_{-2}, and S_{+2} become zero with the probability $\frac{1}{2}^2$.

As a countermeasure, the ith bit is inverted after FEC coding at the transmitter

$$\begin{aligned} T_0(x) =& \sum_{j=0}^{n-1} a_j x^{n-1-j} + a_i x^{n-1-i} + \bar{a}_i x^{n-1-i} \\ =& \sum_{j=0}^{n-1} a_j x^{n-1-j} + x^{n-1-i}. \end{aligned}$$

At the receiver, the ith bit of the receiving bits should be inverted before FEC decoding. Then if the syndrome represents that the ith bit indicates no error, burst detection can be considered to be complete. Fig. 7 explains the bit inversion method.

However, a bit error of a_i at the radio transmission path causes burst false-detection. This probability equals the BER before FEC, and is denoted p.

When one bit shift occurs by UW false-detection

$$S_{-1} = R_{-1}(\alpha) = (a_{-1} + a_{n-1})\alpha^{n-1} + \alpha^{n-1-i} + \alpha^{n-1-(i+1)}.$$

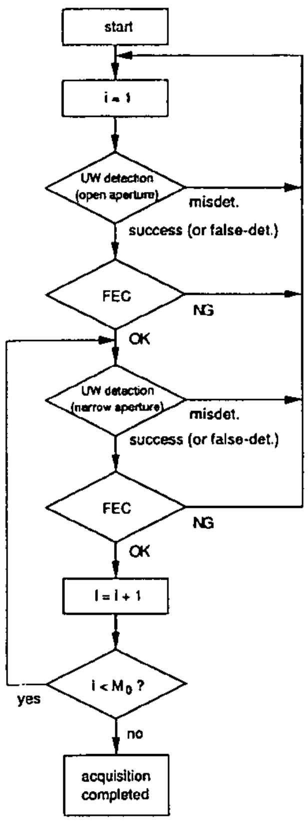


Fig. 8. Flow chart of acquisition control.

Even if $a_{-1} = a_{n-1}$, the syndrome becomes

$$S_{-1} = \alpha^{n-1-i} + \alpha^{n-1-(i+1)}$$

which represents ith bit error and $(i+1)$th bit error. The ith bit error implies that the timing is incorrect. However, when a_{i-1} is corrupted, the ith bit error cannot be detected from the syndrome

$$S_{-1} = \alpha_{n-1-(i+1)}.$$

This generates burst false-detection with the probability of $P_f p/2$.

If the inverted bit is a_0, the probability is relatively large $(P_f/2)$. In order to avoid this, only bits in the middle of the bit line, i.e., $i \cong n/2$, should be inverted.

If the number of bits inverted at the transmitter is q, and the amount of phase shift at the receiver is b-bits, it is considered that the burst false-detection probability is nearly $P_f p^q 2^{-b}$.

C. Initial Acquisition Process

At the beginning of TDMA communications, B-RM synchronizes to the TDMA frame which is transmitted from B-CS. In order to render the false-synchronization probability negligible, initial synchronization is acquired when bursts are detected over M successive frames. When a burst misdetection occurs, the synchronization system is reset to restart the acquisition scheme. When burst false-detection occurs in the M successive frames, false-synchronization is caused. The flow chart of synchronization control using FEC is shown in Fig. 8.

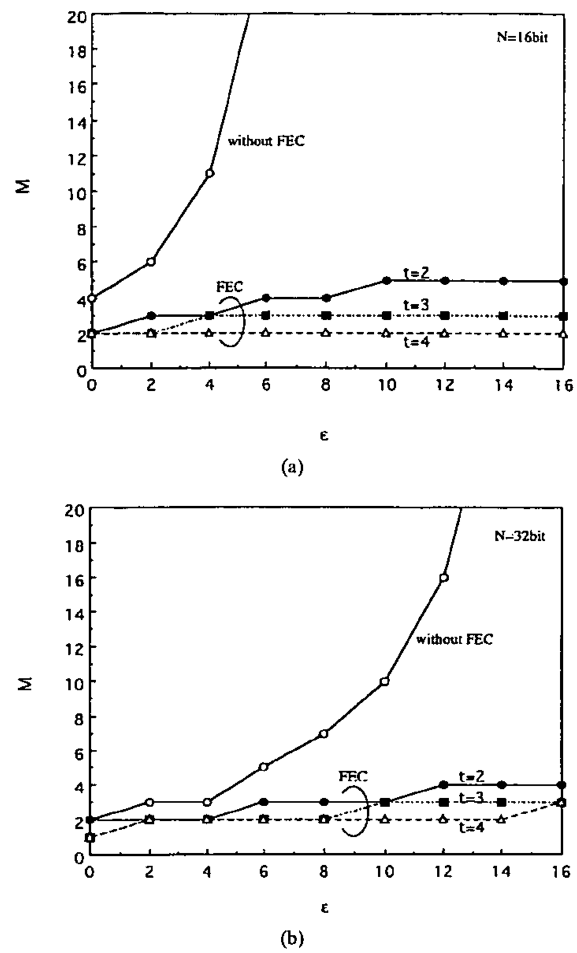


Fig. 9. Calculated value of M.

The probability of achieving acquisition in M frames is $(l - P_m)^M$, and the probability of false-synchronization occurring in M frames is P_f^M, where P_m is burst misdetection probability, and P_f is burst false-detection probability with the narrow aperture technique when a random pattern is input.

The least value of M making the false-synchronization probability lower than the desired value (assuming to 10^{-15} in this calculation) is computed as a function of ϵ. The results are shown in Fig. 9(a) and (b), where the UW length is 16 and 32 bit, respectively. The FEC ability (t) is varied for 2, 3, and 4. The BER is assumed to be 10^{-2}. The value of M is improved when FEC is utilized for synchronization. The improvement is larger as ϵ gets larger, because the UW false-detection is frequent at large ϵ, but it can be rejected by the FEC check.

We also computed the value of M_0, which represents the numbers of the TDMA frames until B-RM can acquire the synchronization at the probability of 99.9%. The results are shown in Fig. 10. When ϵ is small, the UW misdetection probability is large, so the number of frames needed for acquisition exceeds M. The improvement is large when $N = 16$ b. The minimum value of M_0 becomes less than half that when utilizing FEC. When $N = 32$ b, however, the

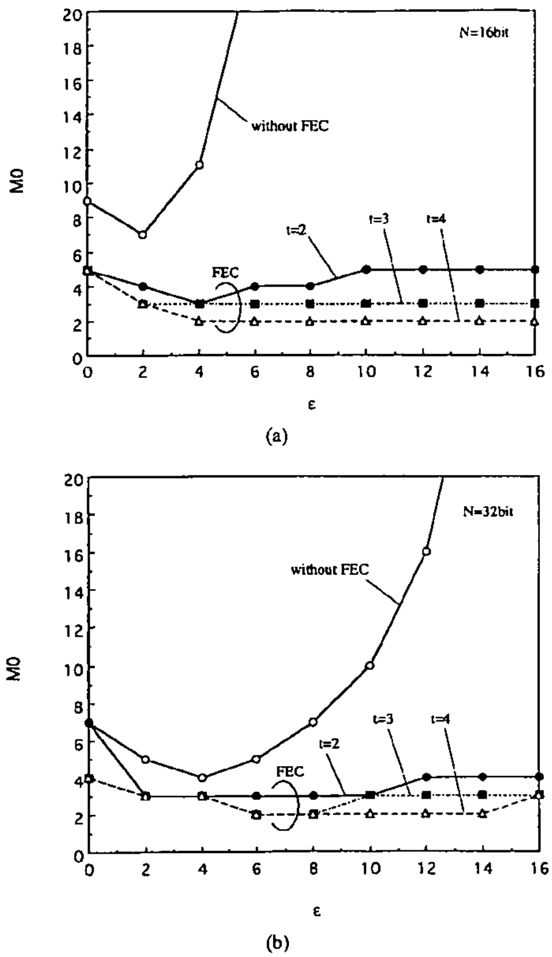


Fig. 10. Calculated value of M_0.

improvement is not so large as the case of $N = 16$ b, because the long UW can make the UW false-detection probability small. While small ϵ is valid in the acquisition scheme because it also makes the UW false-detection probability small, the value of ϵ is generally large considering regular communication after acquisition. If ϵ must be the same in both acquisition and normal communication for control simplicity, the improvement with FEC is large if $N = 32$ b since large ϵ is selected.

IV. Conclusion

First, we proposed the utilization of FEC applied to ATM header, which is indispensable in wireless ATM systems to make cell discard more reliable. Next, we also proposed to utilize this FEC scheme for TDMA synchronization. By combining UW and FEC, we can significantly reduce the number of TDMA frames needed for acquiring synchronization.

When FEC timing is shifted slightly by UW false-detection, the burst false-detection probability increases. This can be suppressed, however, by inverting specific bit(s) among the FEC block code at both the transmitter and the receiver.

Acknowledgment

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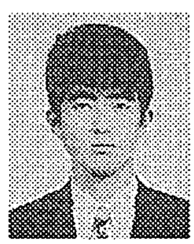

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In 1984, he joined NTT Electrical Communications Laboratories, where he has been engaged in research and development on error correction methods and modulation/demodulation methods in digital microwave radio systems. Currently, his research interests are in multimedia wirelesss-access systems. Presently, he is a Senior Research Engineer at NTT Wireless Systems Laboratories, Kanagawa, Japan.

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Forward error correction schemes for wireless ATM systems

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Abstract:
Wireless asynchronous transfer mode (ATM) systems have been proposed for future broadband multimedia personal communication. Forward error correction (FEC) is often used to improve the bit error rate (BER) performance of wireless transmission systems. The ATM employs header error control (HEC) to protect the ATM cell header from bit errors. Since ATM specifications have been developed for high-quality optical fiber transmission systems, the HEC has single-bit error correction capabilities. However, wireless ATM requires a more powerful FEC scheme to improve the BER performance resulting in a reduction in the transmission power and antenna size. This concatenation of wireless FEC and HEC of the ATM may affect the cell loss performance. This paper proposes an FEC scheme suitable for wireless ATM and analyzes the performance the proposed FEC scheme

Index Terms:
asynchronous transfer mode broadband networks coding errors error statistics land mobile radio multimedia communication personal communication networks ATM cell header ATM specifications BER performance FEC antenna size reduction asynchronous transfer mode bit error rate broadband multimedia personal communication cell loss performance forward error correction header error control optical fiber transmission systems performance analysis single-bit error correction transmission power reduction wireless ATM systems

Forward Error Correction Schemes for Wireless ATM Systems

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Abstract

Forward Error Correction (FEC) is often used to improve the Bit Error Rate (BER) performance of wireless transmission systems. The Asynchronous Transfer Mode (ATM) employs Header Error Control (HEC) to protect the ATM cell header from bit errors. Since ATM specifications have been developed for high-quality optical fiber transmission systems, HEC has single-bit error correction capabilities. However, wireless ATM requires a more powerful FEC scheme to improve BER performance resulting in a reduction in the transmission power and antenna size. This concatenation of wireless FEC and HEC of the ATM may affects cell loss performance. This paper proposes an FEC scheme suitable for wireless ATM and analyzes the performance the proposed FEC scheme.

1.Introduction

Wireless Asynchronous Transfer Mode (ATM) systems have been proposed for future broadband multimedia personal communication [1-3]. In these systems, ATM cells packaged in radio frames were transmitted between a central station and user radio modules.

Some bit errors occurred due to multipath fading, interference or shadowing in wireless systems. Since multimedia services require a high quality level for video or data transmission, Forward Error Correction (FEC) is essential to multimedia wireless ATM systems [4-5].

There are two parameters for estimating FEC for wireless ATM. One is the Bit Error Rate (BER) and the other is cell-loss probability. When an FEC code for an ATM cell is designed to improve sufficiently the BER, cell-loss probability may affect transmission performance. However, if the code is designed with a sufficiently low cell-loss probability, its coding rate decreases. Therefore, combination of two different FEC codes is effective for wireless ATM. The first code is a powerful gain code for the header and the other is a higher rate code for the payload.

First, this paper proposes an FEC scheme using two different codes, one for the header and the other for the payload, and its design and performance. This paper goes on to describe a novel error detection scheme using a re-encoder to discard errant cells. Finally, the performance of the proposed FEC scheme in Rician fading environments is analyzed.

2.Performance of HEC in ATM

This section reviews the performance of Header Error Control (HEC) for the ATM system standardized in the ITU-T and ATM Forum. HEC is a single-bit error correction multiple-bit error detection code that is only employed in the ATM cell header and not in the cell payload in order to avoid incorrect forwarding due to header error. HEC controls 8 redundant bits out of 40 bits in the cell header.

HEC's generator polynomial $G(x)$ is given by

$$G(x)=x^8+x^2+x+1.$$

Since

$$T(x) \bmod G(x)=0,$$

when errors do not occur,

$$R(x) \bmod G(x)=0$$

where,

$T(x)$; transmission bits

$R(x)$; receiving bits.

$R(x) \bmod G(x)$ is called syndrome. There are $256(=2^8)$ syndrome patterns. One syndrome pattern means no error ($R(x) \bmod G(x)=0$). There are 40 patterns indicating single-bit errors ($R(x) \bmod G(x)=x^i \bmod G(x)$ $(i=0,1,2....39)$), and 215 patterns indicating multiple-bit errors. HEC operates in two modes: the correction mode and detection mode. In the correction mode, a single-bit error can be corrected and cells with multiple-bit errors are discarded. In the detection mode, all cells with detected errors in the header are discarded.

Cell-loss probability, P_L, in case of random errors is given as:

$$P_L=P_{det.}(P_a(1)+P_a(2))+P_{cor.}P_a(2)$$

where,

$P_a(0)=(1-p)^{40}$

; probability of no error in one cell header

$P_a(1)=40(1-p)^{39}p$

; probability of single-bit error in one cell header

$P_a(2)=1-P_a(0)-P_a(1)$

; probability of multiple-bit errors in one cell header

$P_{cor.}=P_a(0)$; correction mode probability

$P_{det.}=1-P_a(0)$; detection mode probability

p ; BER before FEC.

Multiple-bit errors create random syndromes. If the output syndrome is one of 41 syndrome patterns according to no error or a single-bit error, it leads to a detection missing.

In case of

$$E(x) \bmod G(x)=0,$$

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it decided as no errors in the ATM cell header, where $E(x)$ is an error polynomial for multiple errors. In case of

$$E(x) \bmod G(x) = x^i \bmod G(x) \ (i=0,1,2....39)$$

it decided that a single-bit error exists in the header, even if multiple-bit error occurred.

Therefore, detection-missing probability is 0.16(=41/256) in the correction mode, and 3.9×10^{-3}(=1/256) in the detection mode.

All double-bit error patterns are properly detected. 2,908 patterns from 9,880 (= ${}_{40}C_3$) triple-bit errors are missed in the correction mode resulting in a detection-missing probability of 0.29 (= 2908/9880). 727 patterns from 91,390 (= ${}_{40}C_4$) four-bit errors are missed as well in the detection mode resulting in a detection-missing probability of 7.95×10^{-3} (= 727/91390).

3. A new FEC scheme for wireless ATM

3.1 Construction of proposed FEC

This section proposes a new FEC scheme that is suitable to wireless ATM. In wireless ATM systems, ATM cells packaged in radio frames are transmitted between a central station and users radio modules, as shown in Fig.1. FEC is often used to improve BER performance and is designed with parameters for BER and cell-loss probability. A straightforward FEC scheme is shown in Fig.2-1. FEC redundant bits are added to an ATM cell including HEC. When an FEC code for an ATM cell is designed to improve sufficiently the BER, the cell-loss probability may affect transmission performance. On the other hand, if the code is designed to achieve a low cell-loss probability, the coding rate decreases. Therefore, using two different codes is effective in designing ATM cells, as shown in Fig.2-2. One code is a powerful coding gain code for the header and the other is a higher coding rate code for the payload. The coded cell is defined as a wireless ATM cell in which HEC is removed and FEC is added. Before creating a coded cell, a single-bit error is corrected and cells with multiple-bit errors are discarded. After this, HEC is removed as shown in Fig.3. When errors after the header FEC are detected, the cells are discarded in the radio section. After the wireless section, a new HEC is generated for a wired section.

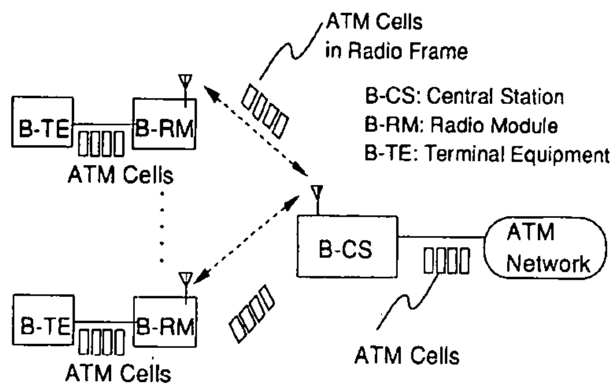
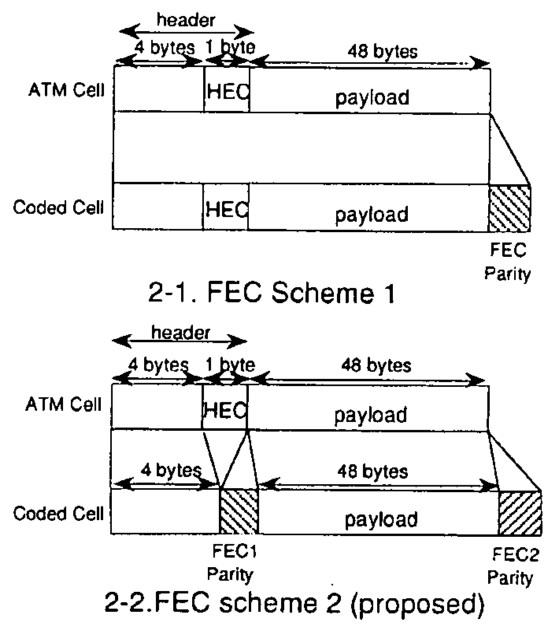


Fig. 1 Construction of Wireless ATM.



FEC1 is for header
FEC2 is for payload
HEC: Header Error Control

Fig. 2 ATM Cell and Coded Cell Format.

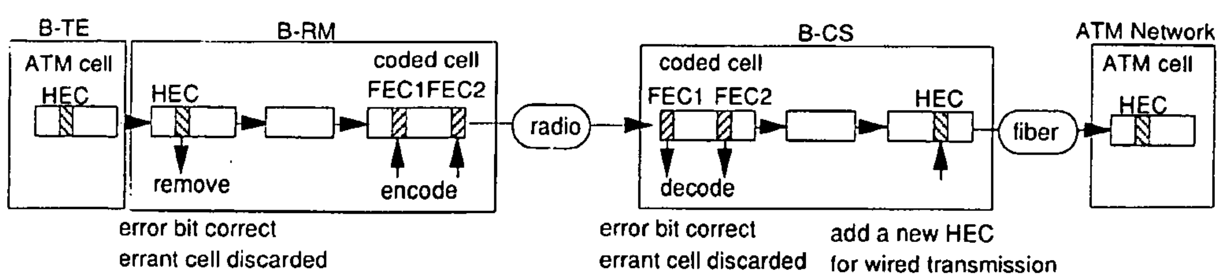


Fig. 3 Adding and removing HEC/FEC redundant bit.

3.2. FEC for payload

BER after FEC P_u in case of a t-bit error correction (n,k) code is given by

$$P_u = \sum_{i=t+1}^{n} {}_nC_i (1-p)^{n-i} p^i i/n$$

where, p is BER before FEC.

Figure 4 shows the BER after FEC versus the BER before FEC. In this case, the payload is divided into two blocks, and coded as a shortened BCH whose original code length is 255. There are several candidates for FEC code, for example, single-bit error corrections (200,192)(coding rate; r=96.0%), double-bit error corrections (208,192)(r=92.3%), triple-bit error correction (216,192)(r=88.9%), four-bit error corrections (224,192)(r=85.7%) and five-bit error corrections (232,192) (r=82.8%). No need to say, codes with higher capabilities produce lower BERs, however, the resulting coding rate is lower.

3.3. Designing method of FEC for header and payload

This section proposes a method for designing an FEC for the header and payload. Cell-loss probability versus BER performance needs to be equal or better when FEC is applied for wireless ATM systems. Cell-loss probability, P_L , is given by

$$P_L = \sum_{i=t+1}^{n} {}_nC_i (1-p)^{n-i} p^i$$

where,

p ; BER before FEC

n ; code length

t ; FEC ability (error bits/ block).

Figure 5 shows relationships of the payload BERs and cell loss probabilities. The dashed line represents the HEC for the header and non-FEC for the payload. The solid lines represent (208,192) double-bit error correction codes for payload and shortened BCH code for a header whose original code length is 63. Codes for the header are (38,32) single-bit error correction (r=84.2%), (44,32) double-bit error correction (r=72.7%), (50,32) triple-bit error correction (r=64.0%), (56, 32) four-bit error correction (r=57.1%) and (62,32) five-bit error correction (r=51.6%) codes. Creating a balanced design for the payload BER and cell-loss probability which is the same as the HEC for a wired ATM is extremely efficient from the viewpoints of coding gain and coding rate.

Figure 5 shows the two bits higher ability of header FEC (four-bit error correction) than payload FEC (double errors correction) is the most similar performance as HEC. Figure 6 shows the performance in case of two bits higher ability header FEC. Header FEC and payload FEC pairs are triple-single, four-double, five-triple-bit error correction. All performances are good balance.

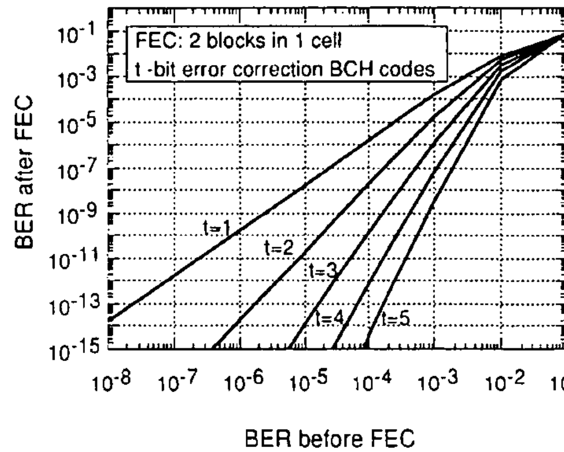


Fig. 4 BER after FEC versus BER before FEC.

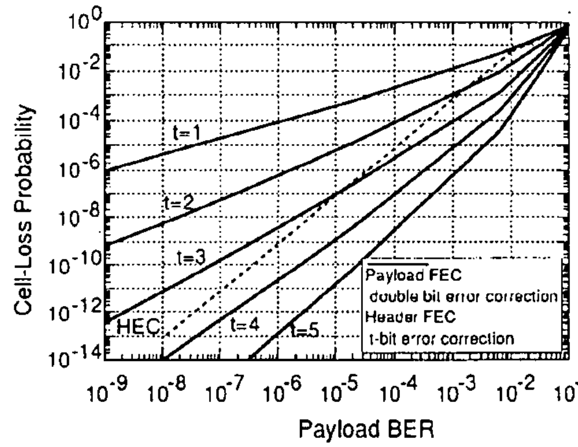


Fig. 5 Payload BER versus Cell-Loss Probability.

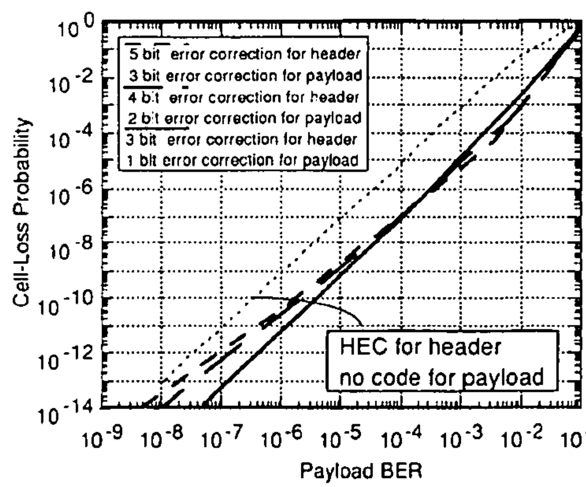


Fig.6 Payload BER versus Cell-Loss Probability.

3.4. A novel error detection scheme using re-encoder

Though the header is protected by a more powerful FEC than the payload, the cell can be discarded when multiple errors occur. This section proposes a circuit for detecting residual errors after decoding.

If HEC is transmitted as shown in Fig. 2-1 and HEC is used to detect residual bit errors after powerful FEC, the probability of detection-missing is still a major problem because HEC's detecting ability is not powerful enough as described in section 2. If another powerful Cyclic Redundancy Check (CRC) is used, many redundant bits are required resulting in a reduction in the frame efficiency. This section proposes a novel error detection scheme using a re-encoder.

The proposed residual error detection circuit is shown in Fig.7. When all errors are corrected by the decoder, no errors occur in the output of the decoder. Therefore, corrected redundant bits (decoder output) are the same as redundant bits from the re-encoder output, as shown as below.

When the FEC code is (n,k) $(m=n-k)$, transmission signal $T(x)$ is given by

$T(x)=I(x)\cdot x^m+(I(x)\cdot x^m)\mathrm{mod}G(x)=I(x)\cdot x^m+P(x)$

where,

$G(x)$;generator polynomial

$I(x)$; information

$P(x)$; redundant bits.

Receiving signal $R(x)$ is given by

$R(x)=T(x)+E(x)$

where,

$E(x)$; error location.

Decoded signal $R'(x)$ is given by

$R'(x)=R(x)+C(x)=T(x)+E(x)+C(x)$

$=(I(x)+E'(x))\cdot x^m+P(x)+E''(x)$

$=I'(x)\cdot x^m+P'(x)$

where,

$C(x)$; calculated error location ,

$E(x)+C(x)=E'(x)\cdot x^m+E''(x)$

$I'(x)=I(x)+E'(x)$

$P'(x)=P(x)+E''(x)$.

Re-encoded signal $R''(x)$ is given by

$R''(x)=I'(x)\cdot x^m+(I(x)+E'(x))\cdot x^m\mathrm{mod}G(x)$

$=I'(x)\cdot x^m+P''(x)$.

When decoding is successful,

$E(x)+C(x)=E'(x)\cdot x^m+E''(x)=0$

$E'(x)=E''(x)=0$

$P'(x)=P(x)+E''(x)=P(x)$

$P''(x)=(I(x)+E'(x))\cdot x^m\mathrm{mod}G(x)=P(x)$.

Therefore, when

$P'(x)=P''(x)$,

it is determined that no error occurs after FEC.

Next, the probabilities of detection-missing for the proposed scheme are discussed. In case of the detection circuit without re-encoder, when an impossible syndrome with less errors than t (FEC ability) is calculated, the cell is discarded.

Therefore, the detection-missing probability P_x is given by

$$P_x=\sum_{i=0}^{t} {}_nC_i\, 2^{-m} \sum_{j=t+1}^{n} {}_nC_j (1-p)^{n-j} p^j$$

where, the FEC code for the header is (n,k) t-bit error correction $(m=n-k)$, and p is BER before FEC.

In the proposed scheme, only when decoded redundant bits are the same as re-encoded redundant bits, detection-missing occurs. Therefore, detection-missing probability P_x' is

$$P_x'=2^{-m} \sum_{j=t+1}^{n} {}_nC_j (1-p)^{n-j} p^j$$

Figure 8 shows the relationship of BER before FEC and the detection-missing probability.

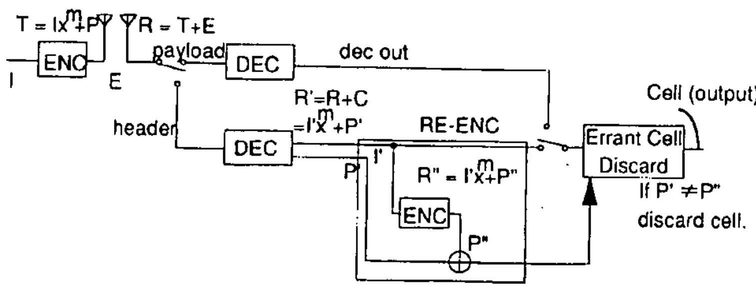


Fig. 7 Block diagram of FEC for AWA .

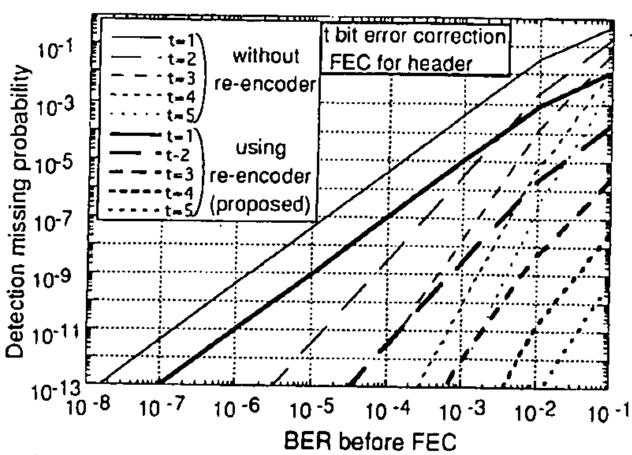


Fig. 8 Detection missing probability.

5.BER performance in Rician fading

This section discuses the effect of the proposed FEC. Super High Frequency (SHF) may be suitable for wireless ATM systems because multimedia services require high speed transmission capability, as high as 10 Mbps. SHF systems require a line-of-sight transmission path. As a result its receiving level is assumed to correspond to the Nakagami-Rice distribution. This section analyzes the performances of the proposed FEC scheme, ignoring the delay spread for simplicity.

Nakagami-Rice distribution is given by

$$f(x)=(x/\sigma^2)\exp(-(x^2+a^2)/2\sigma^2)I_0(ax/\sigma^2)$$

where,

$I_0(x)$; modified Bessel function

x ; receiving voltage

σ^2 ; variance.

One example is shown as followed;

$a=1, a^2/2\sigma^2=5$

SNR γ =30dB at 50% of cumulative probability.

BER of QPSK with coherent detection p_e is given by

$p_e=(1/2)\mathrm{erfc}(\sqrt{\gamma/2})$

where, erfc( ) is an error function.

Figure 9 shows an example of cumulative probability versus BER and cell-loss probability. In the proposed FEC scheme, (56,32) four-bit error correction FEC for the header and (208,192) double-bit error correction FEC are shown. Cumulative probability at a cell-loss probability of 10^{-12} is 50% for HEC and 90% for the above FEC. FEC can improve the cumulative probability or BER performance at arbitrary locations.

6.Conclusion

This paper proposes FEC scheme suitable for wireless ATM and analyzes the performance the proposed FEC scheme. The proposed techniques are followed:

i)An FEC strategy using two different codes for the header and payload, and its designing method for the strategy.

ii)A re-encoder circuit to discard cells in case of multiple errors occurring in excess of FEC's capability.

Furthermore, this paper analyzed the effect of the proposed FEC for wireless ATM for the BER performance in Rician fading.

Acknowledgment

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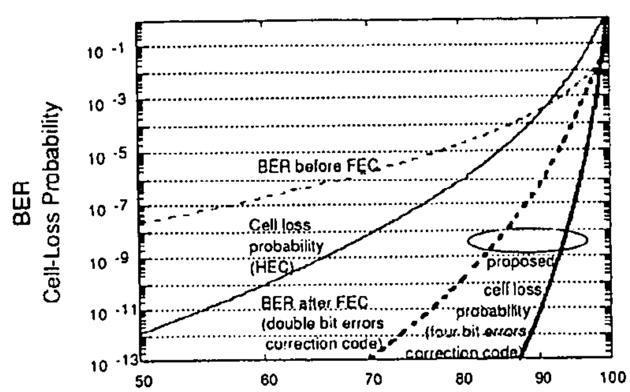

Fig. 9 Cumulative probability under Nakagami-Rice distribution.